Is winter precipitation change over Europe underestimated in current projections?

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Summary

IPCC models project increased winter precipitation over Europe (likely under a high-emission scenario in the 5th Assessment Report). But, how sensitive to model resolution is this increase?

Comparison across CMIP6 climate projections generated with the couple climate model HadGEM3-GC3.1 at five different resolutions.

- Winter precipitation increases substantially more over NW Europe by 2050 at a 50-km-atmosphere–1/12° ocean global resolution than at lower ones.
- The exceptional increase in precipitation is linked to a northward shift and surface warming of the Gulf Stream, which increases extratropical cyclone development in the North Atlantic.
- Further cyclone development is fueled by increased atmospheric diabatic heating and an accelerated upper-troposphere jet over the North Atlantic, because both contribute to weakening atmospheric stability.
- These mechanisms are only at play at the highest ocean and atmosphere resolutions.
- Climate projections relying on traditional ~100-km-resolution models could therefore be underestimating the precipitation increase over Europe in winter, and consequently, the related potential risks.

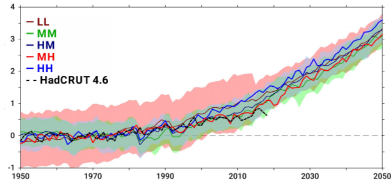
HadGEM3-GC3.1 projections

CMIP6 HighResMIP/PRIMAVERA projections

- Global coupled model HadGEM3-GC3.1
- Period 1950–2050 under a high-emission scenario (SCP5-8.5)
- Table with resolutions and ensemble sizes:

Naming convention	CMIP6 nominal resolution		Ensemble size	
	Atmosphere	Ocean	hist-1950 (1950–2014)	highres-future (2015–2050)
LL	250 km	100 km	8	4
MM	100 km	25 km	3	3
HM	50 km	25 km	3	3
MH	100 km	8 km	1	1
HH	50 km	8 km	1	1

- Similar global climate trajectories:



Global mean surface temperature anomaly over time (K, compared to 1960–1980) of the historical and scenario ensemble means (solid lines) and spread (shading) and in observations (dashed black line).

1. Winter precipitation increases much more in HH than at lower resolutions

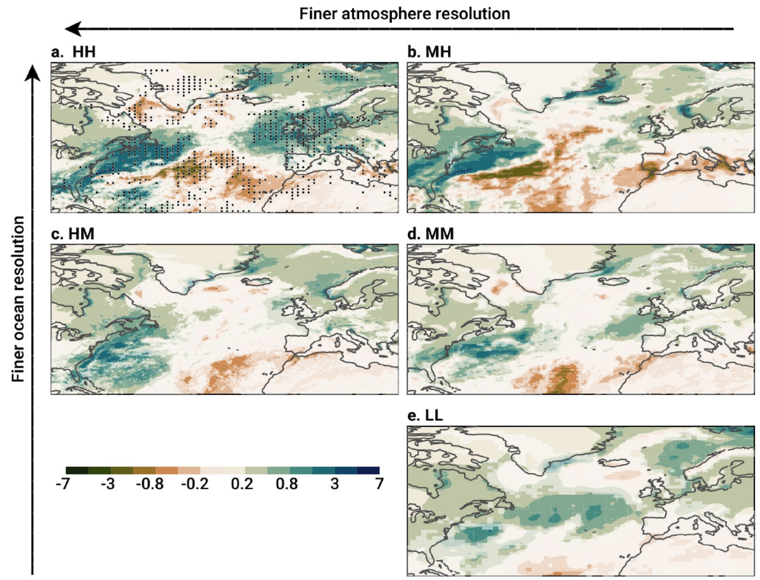


Fig. 1: Anomalies in DJF precip. (mm/day)

- Differences between ensemble means.
- 2030–2050 wrt 1960–1980.
- Statistically significant at the 5% level.
- Stippling on HH plot: anomaly values outside the range of those at all lower resolutions.

Although winter precipitation is projected to increase over NW Europe by mid-century at all resolutions, this increase is substantially larger in HH, at the highest atmosphere and ocean resolution. Below we explain the physical mechanisms underlying this different response.

2. Gulf Stream surface warming in the eddy-rich ocean model only

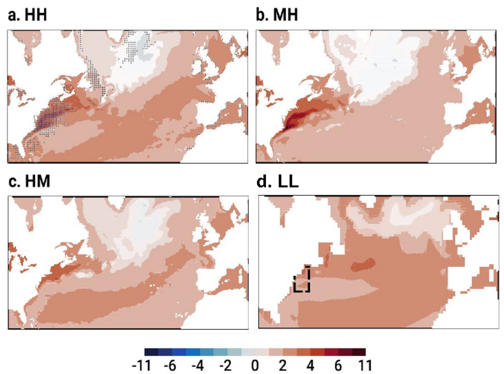


Fig. 2. Anomalies in yearly SST (K; as in Fig. 1)

Only the eddy-rich ocean model (1/12°) in HH and MH projects a northward shift in the Gulf Stream over the 21st century. This shifts causes a northward expansion of the slope waters and, thereby, a strong coastal warming.

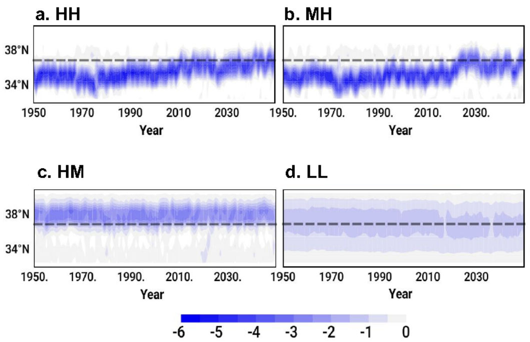


Fig. 3. Change in the meridional gradient (10^6 m/m) in sea-surface height in the Gulf Stream area (square in Fig. 2; left). Dashed line: AVISO 1993–2018 climatology.

This warming is key for the increase in extratropical cyclone activity in the North Atlantic, although it is not the only player (see next). Changes in HM and in MM (not shown) are very similar.

3. Increased extratropical cyclone activity at the highest atmos. resolution

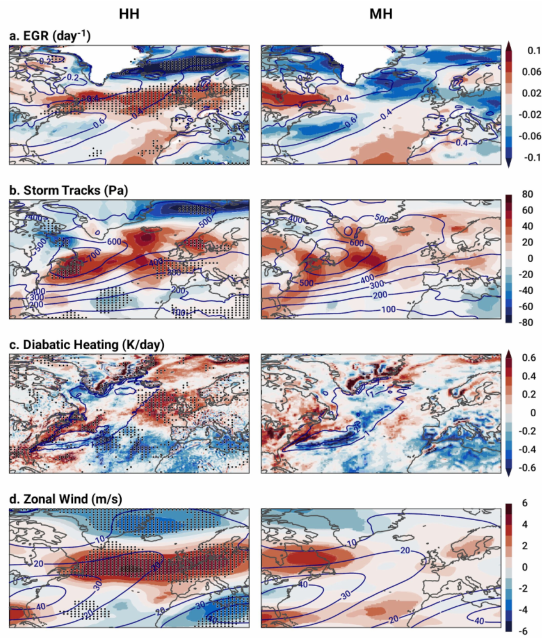


Fig. 4. Anomalies (as in Fig. 1) in DJF

a. Eady growth rate (day^{-1})
b. Storm tracks (Pa)
c. Atmospheric diabatic heating (K/day)
d. 250-hPa zonal wind (m/s)

Contours are the 1960–1980 climatology.

Focus on the differences between HH and MH: why do they show different precipitation response over Europe for a similar Gulf Stream warming?

The Gulf Stream warming increases eddy activity over the western North Atlantic in both HH and MH (a and b, left). Yet only in HH the anomalies extend further downstream over NW Europe, where more active storms explain the increase in winter precipitation.

Only at the highest atmosphere resolution, the Gulf Stream warming leads to increased atmospheric diabatic heating (c, left), likely due to better resolved mesoscale structures. Similarly, enhanced eddy–mean flow interactions accelerate the upper-troposphere jet (d, left), thereby weakening the atmospheric stability. These two processes contribute to increasing storm development over the North Atlantic and are thus crucial to explaining the different precipitation response between the HH and MH.

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